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AIR CUSHIONED LANDING CRAFT (LCAC) BASED SHIP TO SHORE MOVEMENT SIMULATION: A DECISION AID FOR THE AMPHIBIOUS COMMANDER. A (SMMAT) APPLICATION.

by

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13. ABSTRACT

Amphibious forces are the enabling force of choice to globally project rapid and sustainable combat power in the littoral. Whether delivering supplies and equipment for military operations or for humanitarian or disaster relief, the Air Cushioned Landing Craft (LCAC) is the primary surface ship-to-shore movement craft. The time needed to transfer the forces ashore may be critical to operational success and is an important planning consideration. Many factors complicate accurate prediction of this time. Even so, various commanders must use the best available information, given mission priorities and resource and capability limitations, to make numerous tradeoff decisions in planning and executing the movement of forces.

In this paper, a simulation toolbox, the Simulated Mobility Modelling and Analysis Toolbox (SMMAT) is introduced, and a robust LCAC ship-to-shore simulation model is developed as an extension to SMMAT. This model provides the commander a prediction and tradeoff analysis tool for planning and executing the projection of power ashore.

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EXECUTIVE SUMMARY

The Air Cushioned Landing Craft (LCAC) is a tremendously capable amphibious landing craft if operated within its capabilities. But, amphibious commanders and other decision makers do not typically appreciate the unique limitations associated with operating the LCAC heavily loaded and in high winds and seas. When operated outside of its performance envelope, there is the very real and potentially dangerous possibility that degraded craft performance will seriously jeopardize the success of the mission.

As more of the programed over-the-horizon amphibious lift capability enters the Navy and Marine Corps inventories, commanders, will be increasingly likely to conduct amphibious operations away from the shore. This will be particularly important as more sophisticated weapons technologies fall into the hands of third world nations and our operational focus shifts from the open ocean to littoral waters closer to the shore. These longer range operations and an increase the need to be able to plan for and accommodate amphibious lift limitations.

The LCAC is an air cushioned vehicle, supported on a cushion of air trapped inside a rubberized nylon skirt system. With very low surface friction the craft is able to achieve high transit speeds and haul large payloads. However, like any small craft, it is subject to the elements, temperature,

wind, and waves. The performance of an air cushioned vehicle is principally dependent on whether the craft can attain sufficient speed to climb out of the self-created impression it makes in the water. This is known as "hump speed", once over it, the craft accelerates rapidly and operates efficiently. In the event the craft is unable to get over hump it is severely limited in the speed it can achieve (less than 20 knots) and is tremendously inefficient.

Mission planning documents have sought to address these issues with limited success. Mission planning software was developed that incorporates full scale performance testing data and accounts for how wind, wave, and temperature will effect the craft. However this effort is inadequate to overall operations planning. It is limited to consideration of only one craft per iteration, and does not address the operation as a whole.

The purpose of this thesis was to fulfill that operational planning deficiency by developing a decision aid for the amphibious commander. Given a list of ships and their Marine Corps equipment loadout, the amphibious commander or planner can use the simulation tool developed in this thesis to run numerous replications of an entire offload, at varying ranges, configurations, and conditions, to determine his capabilities and the effects of environment and range. This tool enables the commander to make better informed decisions about tradeoffs between conflicting demands.

This simulation was built using the Simulation Mobility Modelling and Analysis Toolbox (SMMAT), a simulation development toolbox that was co-developed by the author as a part of this thesis.

I INTRODUCTION

A. BACKGROUND

The Air Cushioned Landing Craft (LCAC) is a tremendously capable amphibious craft whose unique performance capabilities and limitations, and their impact on amphibious operations as a whole, are not well understood by planners and decision makers. As of this writing, the United States Navy has taken delivery of 67 of the 91 programmed craft[1] and has five amphibious ship classes[2] from which to operate. With a sixth class, the as yet unnamed (LPD-17) class[3], projected to begin delivery just after the turn of the century. A clear commitment to supporting and developing this capability well into the future. The purpose of the LCAC is to provide the

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[1] Splitting assignments evenly between Assault Craft Unit's Four and Five, located in Little Creek, Virginia and Camp Pendleton, California respectively.

[2] Three of the five well configured ship classes have active new construction; the Whidbey Island (LSD-41), the Harpers Ferry (LSD-41CV), a cargo variant of Whidbey Island class, and the Wasp (LHD-1) class, the remaining two welldeck ship classes, Tarawa (LHA-1) and Austin (LPD-4)are in fleet service.

[3] The LPD-17 is the planned functional replacement for 41 ships of the LPD-4, LKA, LSD-36, and LST-1179 classes, with special emphasis on the LPD-4 class with its aviation capability. Currently 12 ships are envisioned with the lead ship delivery projected in FY 02 with delivery of approximately two ships per year thereafter.

Commander of the Amphibious Task Force (CATF) and Commander of Landing Forces (CLF) with rapid transport of wheeled and tracked vehicles and cargo to unimproved landing sites from ships at sea. The LCAC is technologically sophisticated, employing gas turbine propulsion, fly-by-wire flight controls, state of the art craft system monitoring and control, radar, navigation, and communications technologies. LCACs currently cost twenty million dollars each. Their sophistication represents the most significant revolution in amphibious warfare since the introduction of the helicopter. As a high speed non-displacement craft, it effectively opens up 70% of the world's littoral to amphibious operations and makes over-the-horizon (OTH) surface assault possible.

1. Amphibious Fundamentals

Amphibious warfare is one of the most complex and least understood of the modern warfare disciplines. From the Sailor/Infantrymen being put ashore from a colonial *Man of War*, to the enormous scale of the invasion at Normandy, the constant remains the projection of power ashore. Driven by an increasingly capable threat, the changes over the years have been dramatic and the pace of change is rapidly accelerating. The close-in launches of World War II have given way to the over-the-horizon launches of 1990s and beyond.

The amphibious landing force is organized as a Marine Air-Ground Task Force (MAGTF), a combined arms force made up

of command, ground combat, aviation combat, and combat service support elements. The landing force is transported by shipping of the Amphibious Task Force (ATF) into an Amphibious Objective Area (AOA). Ship-to-shore movement is then conducted using embarked helicopters, landing craft, and amphibious assault vehicles (AAVs).

Following World War II, it was no longer practical to carry the entire MAGTF aboard amphibious shipping and the assets of the MAGTF were divided into two components. The assault echelon (AE), defined as the forcible entry capability of the MAGTF, and limited sustainability supplies would now become the force embarked on amphibious shipping. The second component, known as the assault follow-on echelon (AFOE), would be the longer term sustainability and would be carried on prepositioned and commercial shipping in the days following the assault.

The assault echelon is further composed of the assault element, the weapons systems and infantry forces that conduct the forcible entry, and their combat service support equipment and supplies.

There are three amphibious MAGTFs. A Marine Expeditionary Force (MEF) is the largest MAGTF, containing about 50,000 troops, typically including a Marine division, a Marine air wing, and a force service support group. The next size MAGTF is the Marine Expeditionary Brigade (MEB), containing about 15,000 troops and typically including a

Marine regiment, a Marine air group, and a brigade service support group. MEBs can not only be deployed using amphibious ships, but can also be deployed as part of a Maritime Prepositioning Force (MPF)[4]. In this case, the personnel and a small portion of their equipment and supplies fly to a contingency crisis destination where they are met by a squadron of prepositioning ships (Maritime Prepositioning Squadron (MPS)) which contains the bulk of their equipment and supplies. By this means, a substantial Marine force can be constituted in a relatively short period of time, as was demonstrated several times during Operation Desert Shield. The third and smallest MAGTF is the Marine Expeditionary Unit (MEU), which consists of about 2,500 troops and is built around a Marine battalion, a composite air squadron, and a MEU service support group. Typically embarked in three to five ships of an Amphibious Readiness Group (ARG), this Special Operations Capable ARG/MEU(SOC) force unit is typically forward deployed to meet presence commitments and provide an initial response to contingency and crisis.

B. THE PROBLEM

The LCAC is intended to be the work-horse of the amphibious ship-to-shore movement. Operated within its capabilities (payload, environment, and range), it is a

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[4] See Maritime Preposition Force ..., Bates, September 1994, NPS Thesis.

tremendously capable amphibious craft. But operations near and outside the boundaries of that envelope can result in dramatically degraded craft performance and seriously jeopardize overall mission success. The ability of the mission planner and amphibious commander to anticipate and accommodate the influence of environmental, payload, and reliability factors on the overall mission[5] is essential to the success of the amphibious operation. This is particularly true of an operation that is conducted near the edge of the craft's operating envelope.

Operational necessity and competing mission demands often mean that craft will be called upon to operate at the edge. The decision to operate at the boundary (heavy loads, high sea states and/or long ranges) is currently made relying heavily upon Commander's judgement and operator experience supported by guidance in the form of Naval Sea Systems Command, SEAOPS Volume V., and it's associated Mission Planning Software (MPSW). MPSW is a personal computer based tool used to analyze or plan a single craft mission. It takes as inputs, craft load, mission distance, and environmental conditions; and provides a mission GO/NO-GO flag (warning outside envelope) and a craft performance prediction for each leg of the mission; fuel consumed, maximum speed available, and leg times. But, MPSW does not provide a means of combining the

[5] Multiple landing craft servicing multiple ships and/or shore sites - resulting in a dynamic queuing system.

effects on individual LCAC missions into the overall effect on the operation as a whole.

That operational necessity will require craft to operate in heavy seas (where they may be only marginally effective) can best be illustrated by example. During Desert Shield, Operation Imminent Thunder was an high visibility demonstration of amphibious technology; a political mission. Conducted in a high sea state, dramatic television images showed fully loaded LCACs struggling to maneuver in rough seas and conduct "over hump"[6] operations. Fortunately it was only an exercise, as the prevailing winds and seas would have made for an extremely difficult and time intensive ship-to-shore operation. If amphibious forces have to operate in that regime, the mission planners and amphibious commanders must have a good handle on what they are getting into and what they can expect out of the operation. Simply stated, evaluating plans for near edge operations based fundamentally on judgement is inadequate to the task and potentially dangerous. Commanders doing so unnecessarily jeopardize mission success.

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[6] **Over hump**. Hovercraft operating over water make an impression on the water directly beneath them that displaces an amount of water equal to the craft's weight. As the craft moves forward it must literally climb out of the self-produced impression. At approximately 12 to 18 knots, the craft goes "over hump" and leaves its impression behind, rapidly accelerating to high speeds. If the craft is unable to get over hump due to insufficient power available or heavy seas, it limited to sub hump speeds and is grossly inefficient.

1. Strategic Imperative

Ship-to-shore movement from over the horizon (OTH) is an essential capability of current and projected naval expeditionary forces and is a fundamental tenant of the guiding naval strategy "... From the Sea" (O'Keef, Kelso, Mundy, 1992, pp.92-96). A valid OTH capability is envisioned as a triad of high speed, long range complementary force delivery means; a surface delivery craft (LCAC) for transporting vehicles and cargo, a medium lift aircraft (the tilt-rotor MV-22 Osprey), for moving personnel and light cargo, and a swimming armored personnel carrier (the Advanced Amphibious Assault Vehicle - AAAV). The AAAV borne forces are to serve as the initial assault element, clearing the way for the LCACs, relatively large and vulnerable vehicles, to deliver the follow-on weapons systems (tanks, and artillery) and support vehicles once the beach Cushion Landing Zone (CLZ) is secured.

Until the late 1990s, the only triad element that will be in place in any number is the LCAC. This deficiency either forces the LCAC to function in the assault element role, with its increased hazards, or requires implementing some other strategy dramatically influenced by the lack of an over-the-horizon armored amphibian, at least until the AAAV can get into service in the late 1995 time frame. The implication of this triad shortfall is that we will not conduct truly over-the-horizon operations until early the next century. We will,

as today, conduct at best an over-the-horizon mission, followed by the amphibious task force[7], closing the beach to within approximately 15 nm or less, threat[8] and water depth permitting, and conducting the offload ship-to-shore.

The transition of sea-based forces ashore is a critical path phase of expeditionary warfare. Continuous assessment of the impact of environmental, payload, and range factors on LCAC ship-to-shore operations is critical to the overall mission success. To analytically answer questions about an operation as a whole using only the MPSW software, would require that a knowledgeable individual run numerous iterations of the MPSW, determine how the results of each mission iteration would influence the next, and then calculate how multiple craft missions would interact with each other, an analytical task much too complex to accomplish in the time available. Unless the answer to the decision maker's question is obvious to an LCAC expert, typically the Detachment Officer-in-Charge or Craftmaster, the number of controllable and uncontrollable variables to consider prevents answering even the simplest of questions about the ship-to-shore movement phase as a whole and makes follow-on sensitivity analysis questions prohibitively difficult. When the ranges

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[7] Probably a three or four ship ARG, in the case of a humanitarian assistance mission, with a considerable joint service and allied augmentation force in the event of a forced entry.

[8] The primary threat consists of mines, surface-to-surface missiles, and high speed patrol craft.

are long, the sea states high, and loads heavy, the answers are far from obvious.

The purpose of this thesis is to develop a simulation that performs these functions; running the MPSW algorithms multiple times and producing a quantitative result rapidly enough to be useful to the decision maker.

2. Thesis Objective

The objective of this thesis is threefold:

- to develop a basic simulation, a collection of MODSIM II objects fundamental to all logistics mobility and movement orientated simulations, to serve as a core for this simulation, and speed the development process of future related models. This will be a coordinated effort amongst a group of students and faculty.
- to develop a robust decision aid to help amphibious operation planners evaluate plans, and make resource and operation duration estimates.
- to demonstrate the utility of the decision aid for determining overall offload times given a specific list of ships, and cargos, at various combinations of sea state and range.

C. APPROACH

This thesis focuses on illustrating the performance capabilities and limitations inherent in surface ship-to-shore movement of the only in-service element of the previously discussed over-the-horizon (OTH) triad[9] of amphibious warfare,

[9] Amphibious Triad: consists of surface landing craft (LCAC), advanced assault amphibious vehicle (AAAV), and the medium lift aircraft replacement (MV-22 Osprey).

the air cushioned landing craft. A highly robust simulation model based upon the thoroughly tested craft operational performance data of the MPSW was developed as a decision aid and planning tool for amphibious operations planners. The simulation enables analysis of multi-ship and multi-craft amphibious operations as a whole, enabling planners to examine tradeoffs and conduct sensitivity analysis with respect to changing environmental conditions, loads, and ship positions.

From the vision articulated in "...From the Sea", and its precepts, comes the conceptual emergence of Operational Maneuver From the Sea (OMFTS)(Naval Expeditionary Warfare Conference, Nov 1993). The sea based analogue of Maneuver Warfare, OMFTS emphasizes speed and flexibility in the execution of operations, a significant departure from the rigid doctrinal approach of World War II. A tremendous challenge, OMFTS narrows the time window and expands the list of options a commander must consider when determining his plan of execution.

This model is intended to serve as a prototype tool for improving the speed and reducing the uncertainty of planning ship-to-shore movement operations.

The remainder of the thesis is organized as follows: Chapter II, provides an overview of the surface assault, establishing the terms and features of the surface assault to be modelled. Chapter III first motivates the use of simulation as the tool of choice for a decision aid, then

introduces SMMAT, the toolbox. The ground work complete, the study scenario is next presented, followed by a detailed description of the model. Chapter IV is a discussion of the data collection, followed by an analysis of the derived data, including illustrative plots. Conclusions are then drawn and suggestions for further study presented.

II SURFACE ASSAULT OVERVIEW

The objective of the surface assault is to project, at the desired time and place, enabling combat power to achieve an assigned mission. With the advent of OMFTS, where preplanned options are exercised in real time, this model is intended to help the planners and decision makers develop their execution options; including force mixes, operating ranges, environmental effects, and associated tradeoffs.

A. SHIP-TO-SHORE-MOVEMENT

This simulation only regards the ship-to-shore movement phase, the fifth of the classical five phase PERMA amphibious operation; Planning, Embarkation, Rehearsal, Movement to the Objective Area, and Assault. Given that the operation is feasible, (not necessarily obvious to planners if long ranges, high temperatures, and heavy loads are involved), what is a good estimate of how long it will take and how sensitive is it to changes in its parameters? To address these questions the model must be robust enough to account for the effects of environment and payload on both achievable transit speed and subsequently fuel consumption for the landing craft. The model should account for the queuing considerations of various numbers of ships and the landing spots available at the cushion landing zone (CLZ). Each welldeck ship is considered

to be one operational spot, as experience has shown that delays associated with attempting to load multiple craft within a single well outstrip the benefits of simultaneously servicing an increased number of craft.

1. Craft Capabilities and Limitations

The model will be used to determine overall operation times and to optionally collect summary data about the overall operation or about individual craft, such as total fuel consumed, or average time a craft spent loading in a welldeck. The overall operation time is principally a function of craft performance and operational queuing effects. Craft performance is principally modelled in terms of craft speed and fuel consumption, as effected by payload and environment.

2. Ship Location

The model assumes that the initial configuration of the amphibious shipping in the sea echelon area will remain fixed. This assumption is most valid for operations conducted at anchor. It becomes less tenable when ships are underway in some assigned geographical area, as may be required in seas that require the ships to be headed into the seaway to conduct welldeck operations, or when the ship is concurrently conducting flight operations and must maneuver for appropriate winds. If seas are significant, LCAC welldeck entry times can be significantly increased as both ship and craft seek to balance the dynamic forces of wind and wave, using ship course

and speed, to provide a welldeck stable enough for safe entry.

Bringing an LCAC, a relatively small craft hovering on a cushion of air, into a pitching and rolling welldeck can require the kind of attention, nerve and skill normally associated with landing an aircraft aboard an aircraft carrier.

3. Beaches

Beaches are normally approached on a heading nearly perpendicular to the surf line in such a way as to smoothly transition through the surf zone. The beach is crossed at a penetration point that is commonly referred to as the Cushion Penetration Point (CPP), and is followed by an overland translation to the Cushion Landing Zone (CLZ), where the craft is directed to shutdown and unloading operations are conducted. The craft can transit as far inland as the tactical situation, terrain, and embarked vehicle trafficability constraints dictate. Beaches are identified by a color code word, Red Beach, for example, and are characterized by number of craft (spots) the beach can support at any one time.

III METHODOLOGY

A. SIMULATION

"The devil is in the details." - Anonymous.

Amphibious operations are not easy to model analytically. They typically require high levels of fidelity and flexibility, which are difficult to attain, but worth the overhead to achieve. These qualities are essential for accurate modelling of the LCAC performance envelope and subsequently the amphibious operation as a whole. The nature of simulation, particularly object orientated simulation, lends itself well to both fidelity and flexibility issues, therefore the process based, objected orientated simulation language MODSIM II was chosen as the medium for this model. Process oriented simulation is easily understood by seasoned operators lacking formal modelling training, which enables subject matter experts to easily contribute to the methodology. Flexibility is achieved by being able to easily change the simulation parameters and re-run the simulation.

The Goal: to predict offloads time to within one hour. This goal satisfies the needs of ship-to-shore decision makers and planners, giving them the feel of the evolution and providing quantitative information about each modelled scenario. This thesis differs principally from previous NPS

thesis work by (Sumner, 1991), and (Shaw, 1992) in the degree of effort applied to modelling a number of complicating factors, principally environmental parameters and reliability.

The analysis presented in this thesis focuses on overall operation completion time. The model, however, possesses the flexibility to consider numerous other related issues, and provides a significant resource or point of departure for future work. It is built as an extension to the Simulated Mobility Modeling and Analysis Toolbox (SMMAT), described below. The author co-developed SMMAT as part of this thesis effort.

B. SMMAT - THE TOOLBOX

1. Description

The Simulated Mobility Modeling and Analysis Toolbox (SMMAT) is a collection of objects and processes designed to facilitate the modeling of materiel movement along a network. It was designed to handle problems as diverse as battle group vertical replenishment, maritime pre-positioned ship offload, and strategic sealift, and it has the flexibility to handle large or small scale problems. The primary components of SMMAT are junctions, transporters, loaders, and cargo, and the functions provided to allow them to interact. Within SMMAT, cargo is moved between junctions by transporters, and is transferred between junction and transporters with loaders. Delivery can be determined by the route of the transporters,

or can be determined strictly on the basis of cargo destination, with SMMAT automatically selecting the transporter based on transporter availability and compatibility with cargo, junction, and loader.

SMMAT provides several convenient ways to introduce variability into each problem, both during the creation of the scenario, and during the simulation itself. During the creation of the scenario, the number of pieces of cargo at each junction can be varied according to any number of statistical distributions. Additionally, any appropriate characteristic of the cargo (e.g., weight, size, volume, height, number) can be varied for each individual piece using the same distributions. During the execution of the simulation, additional variability is possible by using distributions for load times for each piece of cargo, as well as by introducing reliability into the loaders and transporters, allowing them to break at random and be out of action for a variable repair time.

SMMAT also provides the capability to run replications of the scenario as specified by the user, collecting statistics on any parameter the user is interested in measuring. Upon completion of the replications, SMMAT also provides tools for statistical analysis of the total results.

2. Development

The need for a product like SMMAT was conceived by Prof. Mike Bailey and Prof. Bill Kemple of the Naval Postgraduate School in January 1994, in order to provide a product that would allow students to conduct thesis research on logistics problems on a larger scale than previously possible. SMMAT was developed under their guidance over a nine month period by CPT Don Bates, USMC, LT Bill Roberts, USN, LT Tim Wilson, USN, and the author. SMMAT was developed using CACI MODSIM II (version 1.9.1) on UNIX workstations. SMMAT currently consists of over 50 files totaling more than five megabytes.

The development process followed a strict protocol prescribed by Prof. Bailey. First, each component had to meet the common requirements of the diverse applications being modelled by the developers. Additionally, each object and process was thoroughly tested prior to integration into the toolbox. These test programs have all been retained, and are available for modification and use by future users.

In order to create a framework allowing the creation of vastly different objects, a common data file structure was used, with special data handlers tailored to put the information in the data files into the proper fields of the object being created. Once a basic object has been instanciated, it then inherits other attributes as is

applicable to turn it into a final object capable of performing the required functions independently.

Interest in SMMAT resulted in an invitation to present SMMAT at the 1994 CACI Summer Simulation Conference in Washington, D.C., in August, 1994. Prof. Bailey and the four developers attended.

C. DEMONSTRATION SCENARIO

1. Description

The demonstration scenario consists of a three ship ARG composed of the USS Comstock (LSD-45), USS Cleveland (LPD-7), and USS Peleliu (LHA-5). The three ships are positioned near each other in positions that represent the Sea Echelon Area (SEA) of an AOA. Comstock, being the LSD-41 class, is mother ship to the three modeled LCAC; LC22, LC24, and LC30.

The simulation experiment is conducted by varying the distance to the beach and the weather conditions the simulation runs under. Two weather conditions are modeled, a sea state 1 case, and a more severe sea state 3 case. Ranges to the beach are varied from 5.0 nautical miles in 4 increments out to 50.0 nautical miles for each case.

The simulation begins with the three LCACs departing the well of Comstock with their preloads. One beach is modelled, Red Beach, which has a three spot capacity. As each craft unloads its preload, it checks the ARG ships to determine which ship has the most serials remaining to be

delivered that does not yet have a an LCAC committed to take its next load. Comstock initially possesses seven serials, while Cleveland and Peleliu each possess five. The offload proceeds automatically until all the serials have been delivered to Red Beach, and the serials, modelled as objects, report they are DONE. The simulation then shuts down, and the completion time is collected for later analysis. This cycle constitutes one replication of the simulation. Thirty replications are run for each distance and environmental condition described above.

2. Assumptions

All craft are assumed to be equal and in a standard state of repair and maintenance. The craft are assumed to be completely reliable in the modeled scenario. But, the model possesses the capability of modeling reliability, randomly shutting down craft in accordance with some distribution and restoring them after some repair time has expired.

D. THE MODEL

1. Above The Line

Conceptually a line is drawn between the application developers code and SMMAT. Above the line refers to functionality that is not present in SMMAT, that a new user is expected to provide. SMMAT is a completely functioning and versatile simulation on its own, and was developed to be enhancement friendly. For example, the SMMAT hierarchy of

objects focuses a simple functionality into each object, there are therefore many layers of object inheritance present. For example, ships and beaches both possess the functionality to receive transporters with cargo, this common functionality is located in the basic junction object within the hierarchy of each above mentioned object.

2. Ships and Beaches as Junctions

Junctions are the primary building blocks of SMMAT. The junctions are the highest level objects in SMMAT and rely on the objects within their hierarchy, the basic transporter object for example, to allow them to interact with other objects within the simulation. Each junction possesses some number of loading and unloading spots as well as lists of transporters, loaders, and cargo. The principal function of the junction is to control the flow of transporters docked at it. Once the junction docks the transporter, it tells the transporter to unload, load, and depart. In this simulation, ships are modelled as junctions with only one spot for loading or unloading cargo. Cargo for this model is listed as serials, each defined as one LCAC load. Serials are described in greater detail later in this section. Whenever the ship-junction receives an LCAC-transporter, the transporter, goes through the following steps.

a. Welldeck Entry

The simulated welldeck entry is modelled as a deterministic time to Dock the transporter. An LCAC will expend 5.0 minutes docking.

b. Time In Welldeck

The time an LCAC spends in the well is modeled as a regression function, with a normally distributed perturbing variable, censured at a minimum value of 10.0 minutes to prevent unrealistically low or negative times from being sampled (CNA, 91-267, B-2). This equation has variables to account for how long the welldeck has been idle, the number of loads that have previously come out of the ship, the composition of the serial to be loaded in terms of number of prime movers and number of trailers, and whether fueling was conducted or not prior to departure.

c. Welldeck Departure

Once the craft has been loaded with its serial and determined its next destination, it is ready to depart. Just prior to departing, any fueling time is elapsed, and the craft gross weight is updated to reflect the current payload and fuel state. This information is then passed by the craft to the performance data object (PDObj described below) to be used in calculation the transit speed and fuel consumption for the next leg.

3. Landing Craft

The LCAC is modeled as LCACObj, which inherits and overrides methods of the basic transporter of SMMAT.

4. Serials

Each serial is modeled as a SerialObj, which inherits and overrides the methods of the cargo object of SMMAT. A serial is defined as an LCAC load. Therefore only one is present on an LCAC at any one time. It possesses attributes that identify its weight, and the number of prime movers and trailers. These attributes effect how long it takes to load inside the ship welldeck and the performance capabilities of the transiting LCAC.

5. Performance Data Object (PDObj)

The performance data object contains all the performance tables and correction tables of the MPSW and the methods to produce the appropriate transit speed and fuel consumption to the calling LCAC object. The ***PDObj*** methods call ***WxMan*** (described below) for current environment data when it is required and use extensive interpolation amongst tabled values to obtain the most accurate values achievable.

6. Environment (WxMan)

This object maintains a current weather record, with a value for each parameter any calling method of the ***PDObj*** might require. This object draws records off of a queuelist of records, filled from a user defined data file to simulate

any weather condition, or weather-over-time profile. The user enters a complete weather record into the data file when the user desires any one parameter of weather to change during the run of the simulation. The presented simulation scenario utilized a single record (environmental parameters constant for the duration of the simulation) for each sea state condition as shown in Tables I and II.

Table I. ENVIRONMENT CONDITION 1

Sea State 1

Wind Speed	30.0	knots
Wind Direction	258.0	deg
Wind Gusts	0.0	knots
Ambient Temp	60.0	deg F
Wave Height	2.0	feet
Wave Period	4.0	sec
Wave Direction	102.0	deg

Table I presents the environmental parameters of the first condition. Note the wind direction and speed (wind from 258.0 degrees, at 30.0 knots) relative to the delivery (loaded transit direction is to the East into Red Beach, with the no-payload transit to the West for shipboard recovery and loading) and offload geometry. This condition provides the laden craft a quartering tailwind into Red Beach. Craft then face a headwind as they make their way back to the ships located in their SEA.

Alternately, condition 2 represents an increase in ambient temperature (to 75 degrees from 60) and a wind shift.

Table II. ENVIRONMENT CONDITION 2

Sea State 3

Wind Speed	30.0	knots
Wind Direction	150.0	deg
Wind Gusts	0.0	knots
Ambient Temp	75.0	deg F
Wave Height	4.0	feet
Wave Period	6.0	sec
Wave Direction	120.0	deg

Wind velocity is held constant across the conditions, while the wind direction has shifted (from 258.0 deg. in condition 1, to 150.0 deg. in condition 2), aligning it with its wave direction (120.0 deg.). Condition 2 has the effect of eliminating the tailwind of condition 1 (an aid), and turning it into a headwind (a burden) for the payload laden craft. The fact that the wave direction of condition 2 is closely aligned with the wind (wave 120.0 deg., wind 150.0 deg.) makes for a more difficult transit for the laden craft. This is the principal difference in environmental effects observed between the conditions modelled.

IV DATA COLLECTION AND ANALYSIS

A. BACKGROUND

The simulation was run using eight configurations, four ranges (5, 15, 30, and 50 miles) for each of the two previously detailed environment conditions. A complete offload was replicated 30 times for each configuration. Table III presents the median values for each range-condition combination, and a calculated difference of medians across conditions.

Table III. MEDIAN SUMMARY

Condition median difference

Range	Cond2.	Cond1.	Median Diff.
5	486.75	485.47	1.28
15	713.12	705.03	8.09
30	1083.40	1066.50	16.90
50	1529.60	1513.40	16.20

B. ANALYSIS

Hypothesis testing and graphical analysis were used to determine the significance of the environmental condition and range effects. The analysis objective here is to make inference about the unknown population (overall offload time), based upon the simulation experiment sample data.

1. Environmental Conditions

The hypothesis test for an environmental condition effect is

$H_o : C_2 - C_1 = 0$ (no condition effect on offload time)

$H_a : C_2 - C_1 > 0$ (adverse environmental conditions increase offload time),

From Table III, the differences of median offload times for each range forms the basis for the hypothesis test for condition. Using G, the number of positive differences between medians as the test statistic, the 4 ranges constitute the sample of a binomial distribution, with $p = 0.5$ under H_o. Based upon 4 of 4 median differences being positive, the calculated p-value is 0.0625. Therefore, since this is the smallest significance value that could result from 4 trials, the null hypothesis is rejected in favor of the alternative.

This is equivalent to concluding that in this experiment there is a statistically significant environmental condition effect.

2. **Range**

Figures 1 and 2 are box plots of samples at each range. Clearly offload time increases as a non-linear

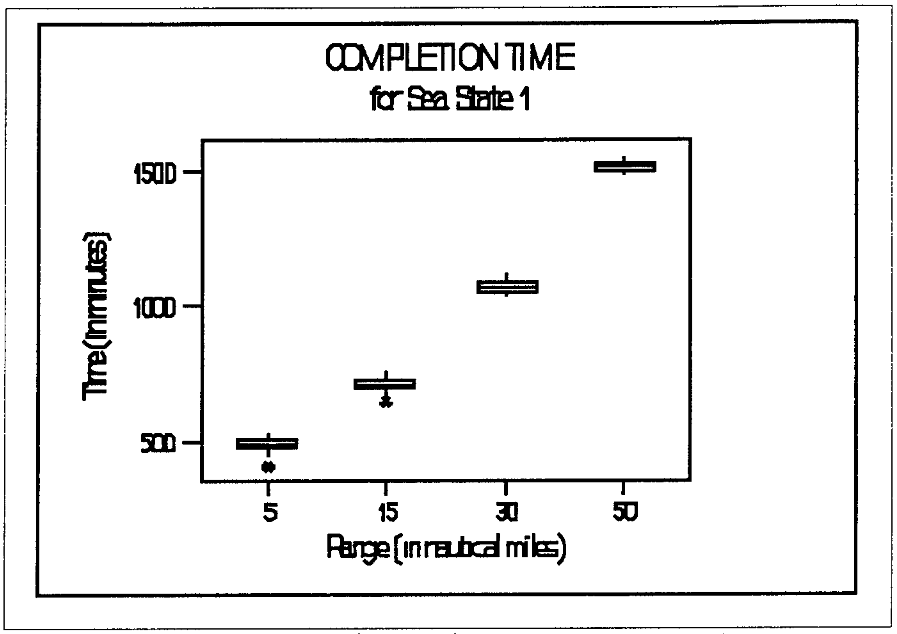

Figure 1. Completion time sea state 1.

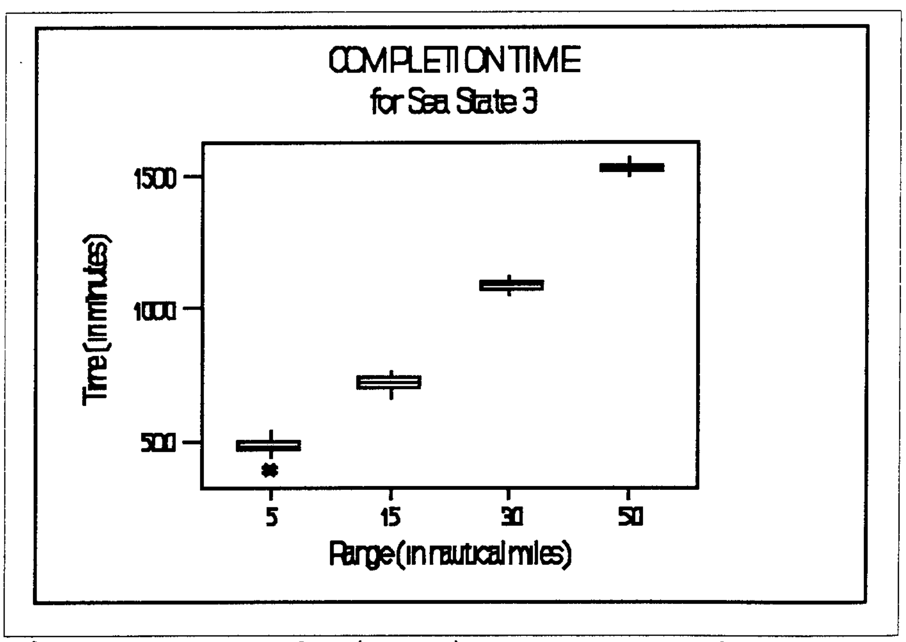

Figure 2. Completion time sea state 3.

function of range under both environmental conditions.

C. CONCLUSIONS

The model has effectively demonstrated the usefulness of the toolbox concept for simulation development utilizing SMMAT. Further, the model demonstrated two critical features of a robust ship-to-shore movement model; by the above hypothesis test, that environmental condition is statistically significant in the observed data; and graphically, that overall offload time is some non-linear increasing function of range. The non-linear function of range was expected and is probably due to the longer transit times at greater distances having a longer period of time for the retarding effects of environment to show up in the overall offload times. The model has demonstrated these characteristics for a typically deploying ARG sized set of ships and serials, incorporating the combined effects of queuing and craft performance, to produce timely quantitative output that would be useful to an amphibious commander as a planning tool.

Recommendations for future work include

- enhancements to the tracking of LCAC crew day within the model, with subsequent detachment manning analysis.
- implementation of higher fidelity Go/No-Go criterion for each craft and the offload as a whole.
- the conduct of offloads using reliability features of SMMAT, to examine the effect of losses due to either enemy fire or equipment failure.

- enhancements to the animation mode of running the model.
- develop the logic to model a ship underway seeking to minimize pitch and role in order to grant a green well.
- solution to operational timing problems. For example, given two loading beaches separated by some distance (say four hours at 10 knots), when and at what speed should the ship depart the vicinity of the first beach toward the second, allowing some LCAC load(s) to pursue the transiting ship, to minimize overall loading time.

To effectively implement the use of this model in operational planning would require shipboard access to high performance personal computing, a Pentium based machine or workstation is recommended. Typically a run of 30 replications required a UNIX workstation 13 minutes to complete.

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